PRESENT STATUS OF ASIAN MONSOON SIMULATION

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1. Introduction

As the Asian Monsoon is one of the most energetic atmospheric phenomena, a large number of studies have been conducted to simulate and understand this phenomenon since the AGCM (Atmospheric General Circulation Model) became available (some of those experiments are summarized in Table. 1 of Lau and Nath (2000)). For example, Shulka (1987) discussed the predictability of the Asian monsoon, using the AGCM simulation conducted by Charney and Shukla (1981). On the other hand, Manabe and Hahn (1981) used their simulation to discuss the influence of the Tibetan Plateau on the Asian monsoon. In 80s, the TOGA program (Tropical Ocean and Global Atmosphere) was initiated, when year-to-year variation of the tropical atmosphere-ocean coupled system became of interest, where ENSO (El-Nino and Southern Oscillation) is one of the most important and interesting research topics. At the same time, year-to-year variations of the Asian Monsoon also attracted interest. In this context, a coupling issue between the Asian Monsoon and ENSO has been appeared. Thus, simulation models of the Asian monsoon contribute to the development of seasonal forecasting and the understanding the mechanism of the Asian monsoon system. The recent development of a climate model has accelerated a simulation of the Asian Monsoon, using the coupled model.

Careful examination of model results is necessary for the improvement in the capacity of models to simulate nature. One of the powerful methods for this purpose is a comparison study, where results of many models are compared each other and with nature. The first such project was the AMIP(Atmospheric Model Intercomparison Project). Using the AMIP results, comparison studies of the Asian Monsoon have been conducted (refer to Sperber and Pamer (1996), Zhang *et al.* (1997), and Kang *et al* .(2002). Additionally, there have been many review papers (Webster and Yang,1992: Yasunari,1991). In particular, recent results of Monsoon research are summarized in a review book edited by Kawamura(2003) and a review of simulation and forecasting of the Asian Monsoon is summarized by Kusunoki (2003). Based on these results, characteristics of the Asian Monsoon simulation will be presented in the following sections.

2. Mean States

In this section, present status of performance of AGCMs for the Asian Monsoon simulation will be presented, mainly based on the AMIP comparison results of Kang *et al.* (2002).

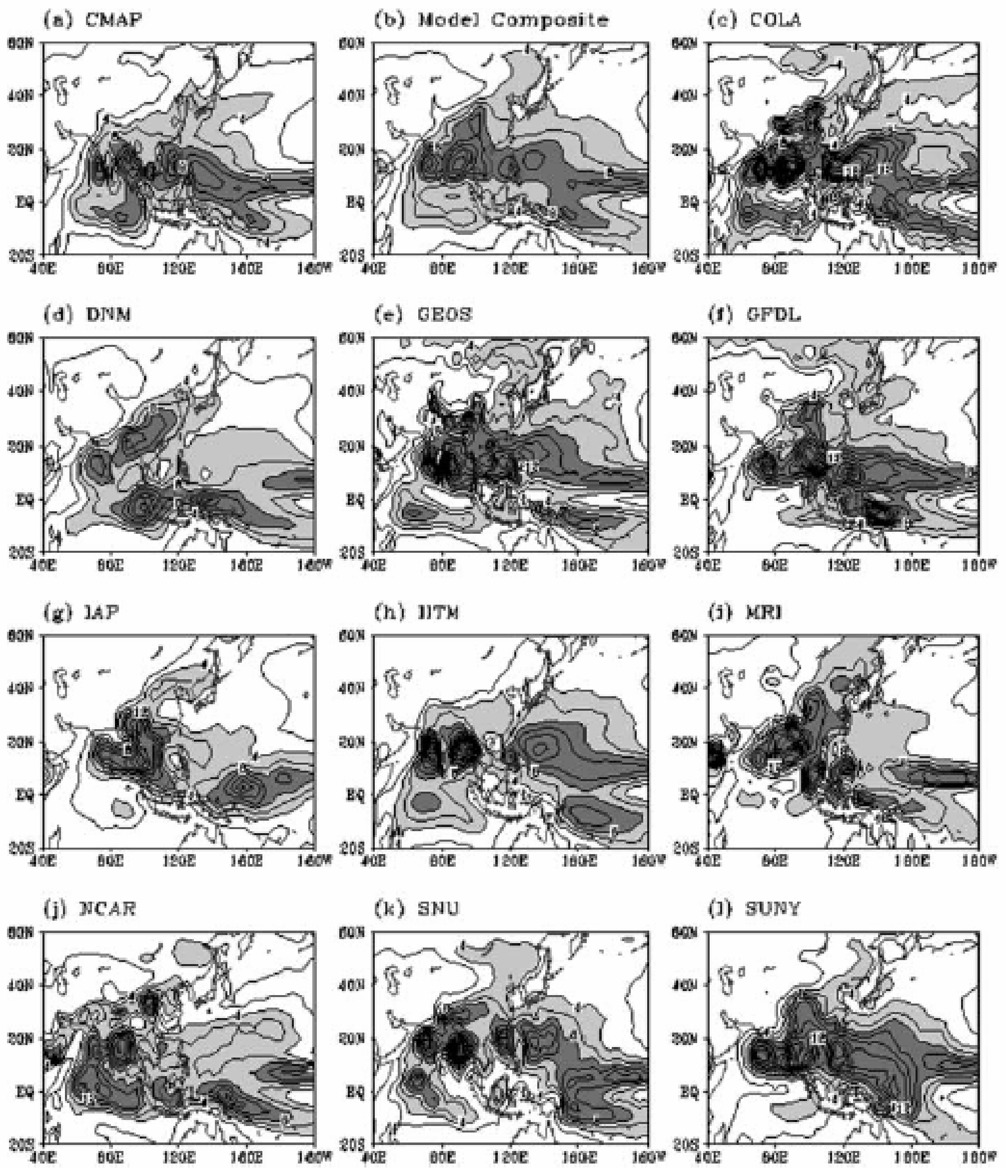

Figure 1 Distribution of climatological summer-mean precipitation for June, July and August. (a) CMAP represents the observation and (b) is an average of model results.(c)-(l) represents each model results.

2.1 Precipitation Fields

In Fig.1, distributions of climatologically summer-mean precipitation for June, July and August of various AGCMs are presented, together with actual observations (CMAP). Here it should be noted that uncertainty exists in the precipitation-climatology. Rainfall estimate over the ocean is improved by using satellite measurements but the rainfall estimates over the data-void land regions are of poor quality. Based on these comparisons, Kang *et al.* (2002) summarized that “the overall spatial pattern of summer monsoon rainfall is similar to the observed, although the western Pacific rainfall is relatively weak”. For the Pacific rainfall, model results can be classified into two categories. One category simulates more rain in the equatorial region and less in the sub-tropical region. The other simulates more rain in the subtropical region. Neither could simulate the Baiu-Chungma-Maiyu front. However, Kawatani and Takahashi (2003) demonstrated that the Baiu front can be well simulated by increasing the horizontal and vertical resolutions.

Liang *et al.* (2001) analyzed the AMIP simulations of the east China monsoon system to study coherent relationships between annual cycle of rainfall and wind biases. A model-to-observation comparison of interannual variability patterns was also conducted to identify the physical processes that contribute to these biases. Biases in the east China monsoon system are concurrently reflected in the planetary circulation, and are associated with differences in model representations of topography. Liang *et al.* (2002) found that China's rainfall interannual predictability is generally believed to depend on the accurate representation of its annual cycle as well as teleconnection with planetary surface anomalies, including tropical east Pacific sea surface temperature and Eurasian snow and soil moisture. A suite of GCM simulations is used to ascertain the existence of these relationships.

As more than half of the world population lives in the Monsoon Asia, it is a critical and important question for the society what kind of changes are supposed to happen in the global warming period. For this purpose, a reliable climate model which can represent the Monsoon variability is necessary. Right now a high resolution climate model (the K-1 climate model), where T106L58 AGCM and 1/4 by 1/6 L48 OGCM are coupled, is now being developed by CCSR(Center for Climate System Research, NIES (National Institute of Environmental Studies) and FRSGC (Frontier Research System for Global Change). The Baiu front has been successfully simulated in the climate simulation (Sumi et al, 2004).

2.2 Circulation Fields

The Asian Monsoon is characterized by westerly flow in the 850 hPa and the easterly jet associated with the Tibetan anti-cyclone at 200 hPa. These features are based on the heat contrast between land and ocean in the large-scale and can be well simulated in the models.

Although the large-scale features of the low-level westerlies are well simulated, there exists regional-scale features. For example, cyclonic flow in the southern part of Indian sub-continent is noted due to the land effect. The westerly flow and easterly flow confluence in the southern China and western Pacific region. These features depends on the well representation of orography and large-scale circulation.

2.3 Seasonal March

The Asian summer monsoon is characterized by a change in winds and an increase in rainfall. Fig. 2 indicates the time-sequence of the pentad precipitation, based on model composites and CMAP observations along 90°E (the Bay of Bengal) and 130°E (the western Pacific). It clearly demonstrates that the onset of the precipitation and its cessation can be well simulated in a climatological sense. It is concluded that the present AGCM can simulate the seasonal march of the large-scale atmospheric circulation associated with the Asian monsoon.

3. Variability on different time scales

3.1 Synoptic Disturbances

Synoptic disturbances such as a monsoon depression and an onset vortex were discussed intensively during FGGE era. After FGGE, observational networks such as radars and satellites are improved and models have been improved. Then, these disturbances are successfully simulated by using a regional model.

Recently, finer structure of rainfall system, especially severe rainfall in the Asian monsoon system has been interested and investigated. For example, severe rainfall events in the Meiyu and Baiu front are investigated. Research studies for simulating meso- α and meso- β phenomena by using a hydrostatic and a non-hydrostatic model have been widely conducted and a lot of new results are being reported.

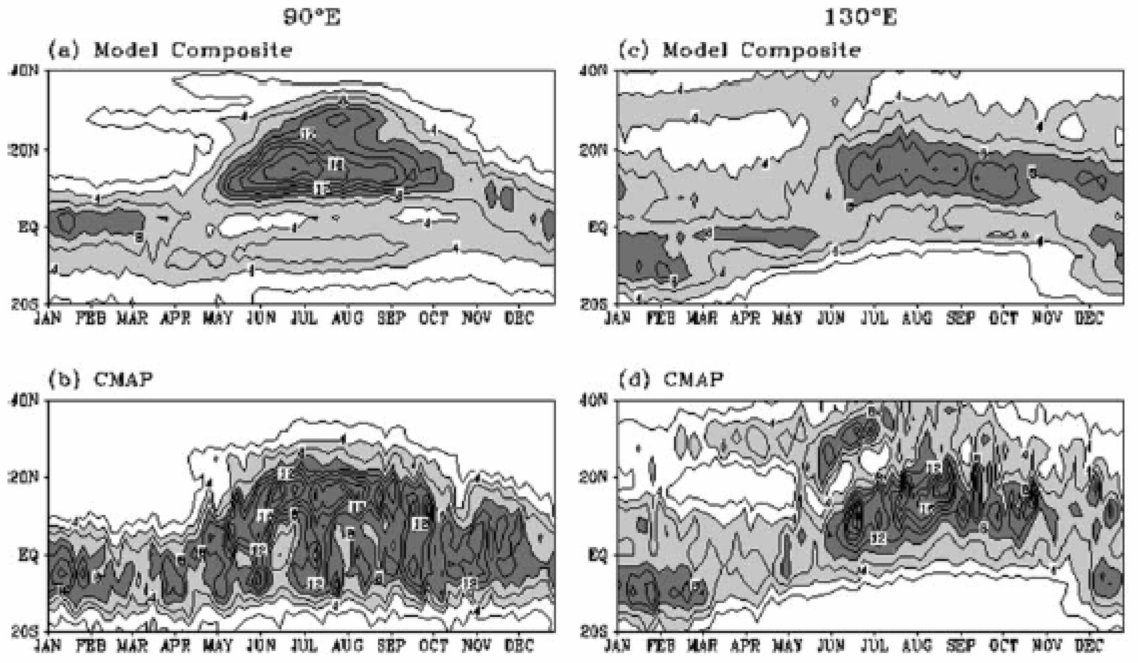

Figure.2 Time-latitude crosssection of climatological pentad-mean precipitation along 90°E (left) and 130°E (right). Results of model composite (observation) are shown in the top (bottom) panel.

3.2 Intraseasonal Fluctuation

The Asian Monsoon is associated with intraseasonal fluctuations. It is characterized by active-break cycles of wet or dry spells. Its time-scale is relatively broad and its period extends from 20 days to 50 days. One of the most dominant and interesting intraseasonal fluctuations is the MJO (Madden-Julian Oscillation) (Madden and Julian, 1971) and the simulation of the MJO has been widely conducted at the various Research Institutes. Slingo *et al.* (1996) has discussed the performance of many GCM results of an intraseasonal fluctuation by using the AMIP results. They concluded that simulations of the intraseasonal fluctuation in the tropical region represent smaller amplitude and shorter periods.

The northward propagation of the intraseasonal fluctuation over the Indian Ocean sector is a unique phenomenon associated with the summer Asian Monsoon. It was not well simulated in the AMIP run (Lau *et al.*, 1996); however Kar *et al.* (1997) demonstrated that it could be simulated by increasing the horizontal resolution. This result is consistent with the high resolution climate model (refer to Section 3.1).

Another important aspect is the coupling between the atmosphere and the ocean. Recently, the role of air-sea interaction in the variations of the Asian Monsoon has been recognized by many authors. Wang *et al.* (2000) emphasized this in the WPH (Western Pacific High) anomaly, corresponding to ENSO (refer to section 4). This coupling role is also discussed for the MJO. Recently, three modeling groups (IPRC/UH, MRI and SUNY) presented the results indicating that inclusion of air-sea interaction could enhance the model simulation of MJO and monsoon northward propagating ISO (Wang *et al.*, 2004)

3.3. Inter-annual Variability

Inter-annual variability of the Asian Monsoon is addressed by using AGCM with prescribed SST and the coupled model.

Numerical experiments with prescribed SST are based on the concept that these inter-annual fluctuations in the Asian Monsoon are caused by the inter-annual fluctuation of the surface forcing, such as SST, snow cover, etc. Sperber and Palmer (1996) conducted a comparison study of 32 models for the period 1979-1988, using the AMIP results. They found that the Asian Monsoon variability is not well simulated, even though SST is specified. They concluded that only the most Northerly rainfall can be skillfully predicted. Furthermore, it is demonstrated that the Webster and Yang index (wind shear) is better simulated than the all-India rainfall. With respect to Webster and Yang index, there are many discussions as to whether it really represents the Asian Monsoon. Furthermore, it is concluded that interannual variability is better simulated in models which are able to generate a better climatology. This is considered to be a general principle in developing a model. After model revision, simulation of the interannual variability over the Asia was improved very much (Sperber *et al.*, 1999). This suggests that continuous model improvement is a critical factor in obtaining a better simulation of the Asian Monsoon.

The impact of the land surface conditions and the snowfall over the Eurasian continent have been investigated by many researchers(Yasunari,1991;Dirmeyer(1999)) It is reported that the land surface condition in Spring has an impact on the following summer monsoon. Shen *et al.* (1998) have investigated the impact of the Eurasian snowfall and concluded that it plays a part but does not overwhelm the SST-impact.

The interannual variability of the Asian Monsoon has been investigated by using the coupled atmosphere-ocean model. Kitoh *et al.* (1999) found that the MRI-CGCM was well able to reproduce the ENSO-Monsoon relationship. Lau *et al.* (2004) noted that the ENSO-East Asian Monsoon relationship is realized in the GFDL CGCM through the WPH (‘Western Pacific High) anomaly mechanism (Wang *et al.*, 2000). This has been confirmed by using historical data (Zhang *et al.*, 1996).

3.4 Decadal Variability and Long-term Trends

Decadal variability in the Asian Monsoon is widely known. For example, 2 year cycle was dominated in the Asian Monsoon system before the middle of 1970s, but 4 or 5 year cycle becomes dominant after the middle of 1970s. However, it is not well understood whether this is a modulation of the Asian Monsoon system or the existence of the decadal mode. Research on the decadal variability of the Asian Monsoon is not sufficient and further studies are necessary in the future.

Another important issue is a climate change of the Asian Monsoon corresponding to the Global Warming. As SST influences very much to the Asian monsoon in the present climate, it is a critical factor what is the SST change when the global warming occurs. Many models show the El-Nino type change of SST when global warming occurs. Based on this change, it is imagined that the Asian Monsoon become more active in the warmed climate and heavy precipitation is worried. At the same time, the Ohotuku High is expected to be strengthened. This regional climate change will be discussed further.

4. Factors to Contribute to the Simulation Performance

4.1 Resolution

Sensitivity of to the performance of the Asian Monsoon simulation to horizontal resolution has been investigated by many researchers. Sperber *et al.* (1994) investigated the sensitivity by using T21, T42, T63, and T106 of the ECMWF model, and concluded that performance of T21 was generally better than the others. However, this conclusion was relatively subjective and has not been accepted. Stephenson *et al.* (1998) investigated the sensitivity by using T21, T31, T42, and T63 of the ARPEGE model. Brankovic and Gregory (2000) investigated the sensitivity by using 180km, 110km and 55km of the ECMWF new model and concluded that orography is better represented as the resolution is increased and the rainfall associated with orography is well represented. In general, when the horizontal resolution is increased, orography representation and atmospheric flow and precipitation predictions all improve.

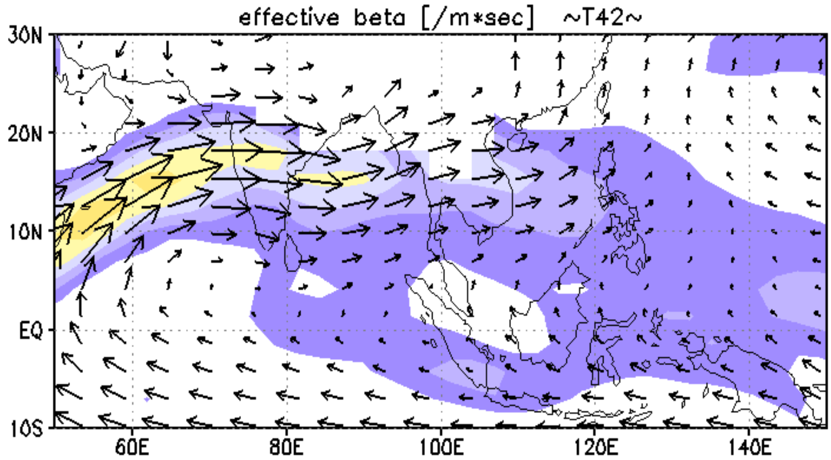

Figure.3 June, July and August mean of wind fields at 850 hPa for observation (top), T106 model simulation (middle) and T42 model simulation (bottom). Effective beta-values are also presented in the figures.

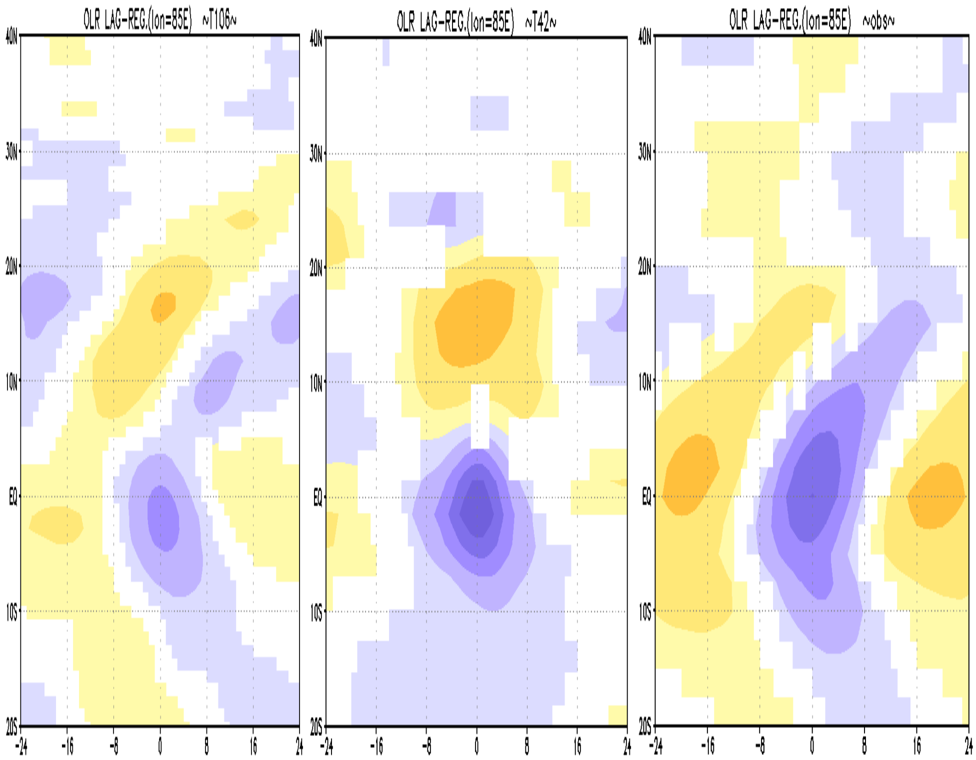

Figure.4 Lag correlation of OLR in the Indian Ocean for T106 model (left), T42 model (center) and observation (right).

For example, the northward propagation of the intra-seasonal fluctuation over the Indian Ocean sector can be observed in Fig.3. This is well simulated in the T106 simulation but not in the T42. This is because the large-scale flow around the Indian sub-continent is improved with a corresponding improvement in the response to convective heating in the equatorial Indian Ocean. The July monthly mean of 850hPa wind fields are presented in Fig.4. It is demonstrated that cyclonic flow in the southern part of the Indian sub-continent is improved due to an improvement in the representation of the Indian sub-continent.

44.2 Convection Scheme

4.2 Convection Scheme

There are many studies investigating effects of cumulus parameterization on the Asian Monsoon simulation. Although it is true that cumulus parameterization scheme has a large impact on the simulation result, it seems that no definite conclusion has been obtained. Recently, finer resolution has become available because of the increase in computer power and the parameterization of convection in a fine resolution model is now a critical issue, as has been discussed in the meso-scale modeling or regional modeling area. How to handle convection in a model is a problem common to various models. A close collaboration among various modeling groups (large-scale modelers, meso-scale modelers, and cloud modelers) is recommended. It is certain that simulation of the Asian Monsoon will improve with the development of better parameterization schemes.

4.3 Land Surface Process

The effects of the soil moisture and snow cover over the Eurasian continent amongst the main topics concerning the Asian monsoon variability. For example, Yang and Lau (1998) examined the impact of SST and wet land surface forcing. Shen *et al.* (1996) investigated the impact of soil moisture over the land and concluded that the effects of land surface condition do occur, although impact of the SST appears to be larger.

The interaction between land and atmosphere is characterized by complex land-surface conditions and orography. In particular, urban and man-made land conditions such as rice fields should be taken into account, as a model resolution becomes finer.

Another important aspect is the effect of complex terrain in the land-atmosphere interaction. Local circulation, such as that due to mountain-valley winds, can transport heat and moisture on a daily time scale. This may have a strong impact on the interaction between free atmosphere and the surface in mountain regions. There is a need to develop a transfer scheme between energy and water which includes this sub-grid scale orography.

4.4 Coupling with the Ocean

As the ENSO-Monsoon relationship is one of the most important issues, it has been intensively investigated using an atmosphere-ocean coupled model. Latif *et al.* (1994) investigated the climate variability by using the MPI climate model and concluded that simulation of the Indian monsoon was inadequate. Nagai *et al.* (1995) found that the ENSO-monsoon relationships were noted in the MRI coupled model. Meehl and Arblaster (1998) has examined CSM results and concluded that CSM simulation in the Indian Ocean has errors because of an error in SST of the Indian Ocean used by CSM. Kitoh *et al.* (1999) found that MRI-CGCM reproduces the broad-scale features of the Asian monsoon reasonably well, together with the observed ENSO-related interannual variability. On the other hand, Chang and Li (2000) presented a conceptual model for TBO (Troposphere Biennial

Oscillation), which considers a land-atmosphere-ocean coupling. It is obvious that an interaction between atmosphere, land and ocean must be represented properly in a climate model and considerable attention should be paid to this aspect.

Recently, a coupled model simulation has also been used for the intra-seasonal fluctuation such as MJO, with the presentation of interesting results. This results from the recent progress of the coupled model. It is suggested that a coupled model can simulate the MJO better than the AGCM. Whether or not a predictive skill for the seasonal forecast is improved by the use of a coupled model is a target of future research.

Another important application addresses the issue of global warming. The issue of the change in the Asian Monsoon resulting from global warming is of extreme importance because almost half of the world population lies in the Asian monsoon region and the most vigorous economic growth is expected in this region. A more reliable climate model is necessary in order to answer this question.

4.5 Process Studies and Usage of Regional Models

The above-cited matters are related to an issue of improvement of physical processes. In order to achieve these goals, carefully designed experiments and analyses are necessary. In this regard, a regional model or a limited-area model is a powerful tool. Furthermore, a non-hydrostatic model can be used in the simulation. Present status of the regional climate modeling is summarized in the review paper by Wand *et al.* (2004). Examples of the application of regional climate models to the Asian Monsoon case are relatively scarce and further efforts should be made in the future.

4.6 Treatment of Clouds

Observations indicate that the East Asian summer monsoon shows distinctive characteristics of persistent and heavy rainfall, which are intimately related to the clouds. Cloud-climate interaction is therefore an important mechanism in deciding the climate states primarily through the latent heat release and radiative effects of clouds. Wang *et al.* (2004a) examined both the observations and AMIP model simulations of the cloud radiative forcing over East Asia and found that the clouds provide a significant radiative cooling over this region versus the same latitudinal bands in the Northern Hemisphere. Since the cloud radiative forcing is a bulk variable involving several cloud parameters (cover, microphysics, liquid/ice water, and the radiation fluxes), it would be ideal to use it for evaluating and comparing the climate simulations from the AMIP-and CMIP-II models without considering the different parameterizations for the cloud parameters adopted in the models. Due to the broad spectrum of cloud scales, it is a challenging task to represent clouds as well as their effects in the climate models with coarse resolution.

5. Summary

Numerous studies, using numerical models, have been conducted for the purposes of simulation and forecasting. Main purposes of simulation study are the validation of climate models and understanding of mechanisms of nature. In general, these studies are driven by an interest in a specific aspect of the Asian Monsoon, and such an issue-driven simulation study should be further developed.

At the same time, continuous effort should be conducted to improve a performance of AGCM and CGCM. For this purpose, careful comparison of model results with observation is necessary. Particularly with the advent of increased computer power, the necessity for improvement in understanding of the physical processes involved is widely acknowledged. Skill in simulating the Asian Monsoon is expected to be improved as a result of this effort in continuous model development.

From a viewpoint of simulation, it may be concluded that models are well able to simulate broad-scale features and the seasonal march of the Asian Monsoon. In general, it may be thought that a model which is well able to simulate the horizontal distribution of climatic states can also well simulate a temporal fluctuation of the variables. Intra-seasonal and inter-annual fluctuations are still important issues for simulation because the former is associated with an active-break cycle of the Asian Monsoon, whilst the latter is associated with the year-to-year variation of the Asian Monsoon.

Although the abilities of models are very much improved, there still remain many issues. In particular, there is the challenge of how to handle cumulus parameterization. A cloud resolving model for monsoon simulation is now available. By using different models, more light may be shed on the parameterization issue. Another important issue concerns aerosols. As is widely known from the Asian Brown Cloud (ABC), natural and anthropogenic aerosols are rife in the Asian Monsoon region. Interaction between aerosols and clouds require further study.

At present, more concern will be paid to regional features in the Asia Monsoon region. In other words, small scale and short time-scale phenomena are targets for simulation.

It should be emphasized that the accuracy of CGCM approaches comparably that of the AGCM. This means that the interannual fluctuations of the Asian Monsoon can be investigated using the coupled system. Future Asian monsoon prediction may be possible through the use of this coupled model.

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